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(54) Method and apparatus for detecting friction coefficient of road surface, and method and system for four-wheel steering of vehicles using the detected friction coefficient of road surface.

(57) An method for detecting a friction coefficient (μ) of the road surface according to the present invention comprises a detection step of detecting an operating angle (θ_H) of the steering wheel (4) of the vehicle, a vehicle speed (V) and an operating pressure (ΔP) of the hydraulic power steering unit (1) for the front wheels (FW), and a calculation step of calculating the friction coefficient of the road surface on turning of the vehicle by considering relationships among a slip angle (βf) of the front wheel, the friction coefficient of the road surface and a cornering force (C_F) of the front wheels. The method according to the present invention further includes a step of prohibiting the execution of the calculation step when the steering wheel is turned back, whereby the calculation step is executed only when the direction of the operating pressure of the power steering unit is in the equiphase with the operating direction of the steering wheel. Also, the four-wheel steering system according to the present invention has a rear steering actuator (11) for steering the rear wheels (RW) so as to increase the steering angle of the rear wheels as the friction coefficient of the road surface calculated by the above-described method decreases.

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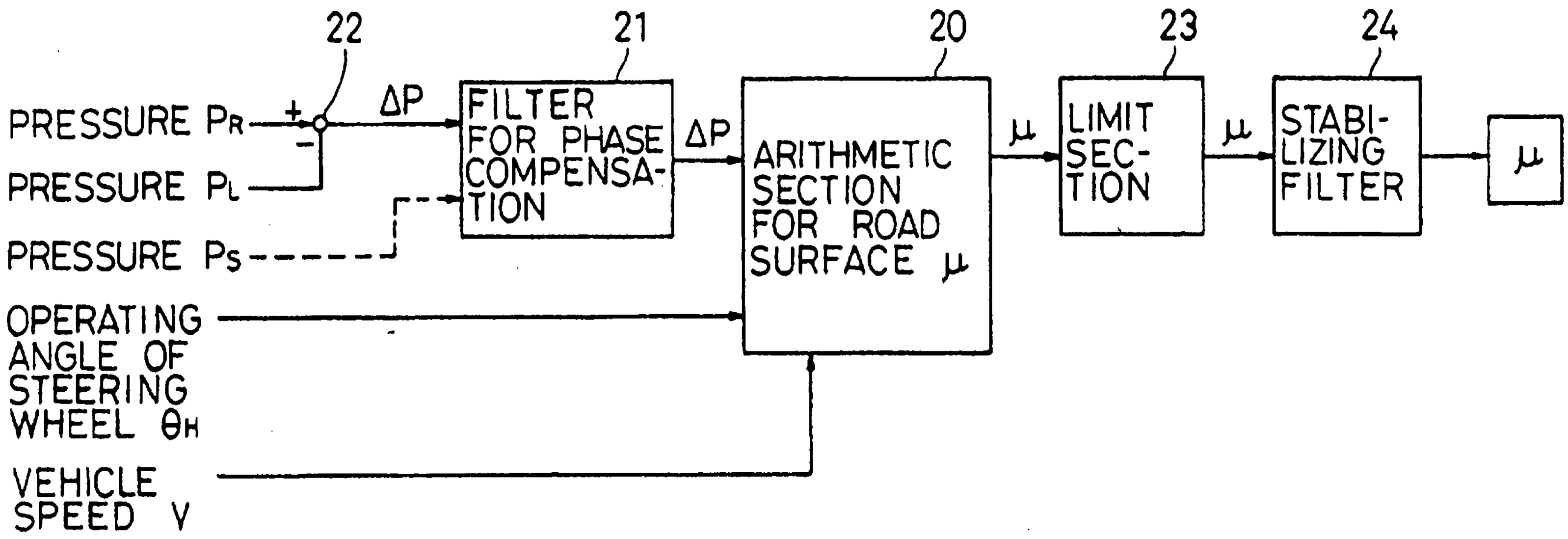
FIG. 3


22
21
20
23
24
PRESSURE P_R
+
−
PRESSURE P_L
PRESSURE P_S
OPERATING ANGLE OF STEERING WHEEL θ_H
VEHICLE SPEED V
ΔP
FILTER FOR PHASE COMPENSATION
ΔP
ARITHMETIC SECTION FOR ROAD SURFACE μ
μ
LIMIT SECTION
μ
STABILIZING FILTER
μ

BACKGROUND OF THE INVENTION

Field of the Invention

Firstly, the preset invention relates to a method and an apparatus for determining the ease of slip on road surfaces on running vehicles, that is, for detecting the friction coefficient of road surface. Secondly, the present invention relates to a method and a system for four-wheel steering of vehicles in which the steering of rear wheels is controlled by using the detected friction coefficient of road surface, when the front wheels of vehicle are steered.

Description of the Related Art

The method for detecting the friction coefficient of road surface and the method for four-wheel steering of vehicles have been disclosed, for example, in Unexamined Japanese Patent Publication No. 60-148769 (US 4,964,481, DE 3,500,797, GB 2,153,311, FR 2,558,130). According to the former method of these two known methods, the friction coefficient of road surface is detected on the basis of the operating angle of steering wheel of vehicle, the vehicle speed, and the lateral acceleration acting on the vehicle body. According to the latter method, the steering angle of rear wheels on vehicle is corrected in accordance with the friction coefficient of road surface detected by the former method.

The above-described method for detecting the friction coefficient of road surface will be explained below in more detail. First, the slip angle of front wheel is calculated from the operating angle of steering wheel and the vehicle speed. The slip angle correlates with the cornering force of front wheel, and the cornering force varies with the friction coefficient of road surface. Meanwhile, it is well known that the cornering force is proportional to the lateral acceleration acting on the vehicle body. If the operating angle, the vehicle speed, and the lateral acceleration are detected, therefore, the friction coefficient of road surface can be calculated on the basis of the detection results.

The lateral acceleration which the vehicle body is to be subjected during the turning of vehicle actually acts on the body only when some time elapses after the start of turning. Since the lateral acceleration acts on the vehicle body with a delay after the start of turning of the vehicle, there is a delay in detecting the lateral acceleration of vehicle body. For this reason, the friction coefficient of road surface cannot be calculated quickly by the above-described method.

The cornering force calculated from the lateral acceleration acting on the vehicle body is equivalent to the sum of the cornering forces generated on the front and rear wheels. When the friction coefficient of road surface is calculated on the basis of the cornering force obtained from the lateral acceleration, therefore, the slip angle of not only the front wheels but also the rear wheels should be taken into consideration. With the conventional method, in which the slip angle of front wheels only is taken into consideration, the friction coefficient of road surface cannot be exactly detected, resulting in poor accuracy of the detected friction coefficient of road surface.

SUMMARY OF THE INVENTION

The first object of the present invention is to provide a method and an apparatus for quickly and accurately detecting a friction coefficient of the road surface at the initial turning stage of vehicle. The second object of the present invention is to provide a method and a system for four-wheel steering of vehicle in which the steering control of rear wheels can be performed in an optimum manner when the front wheels are steered.

The first object can be achieved by the method and apparatus for detecting a friction coefficient of the road surface according to the present invention, the method comprising:

a first step of detecting each of an operating angle of the steering wheel of the vehicle, a speed of vehicle and an operating pressure of a hydraulic power steering unit for the front wheels of vehicle,

a second step of detecting a proper steering situation in which a condition of increase in the operating angle of front wheels is satisfied during the operation of steering wheel, and

a third step of calculating a friction coefficient of the road surface on the basis of the data detected in the first step only when the proper steering situation is detected.

In the third step, the friction coefficient of road surface is calculated by using relationships of three conditions; firstly, a slip angle of front wheels is determined in accordance with the operating angle of steering wheel, the vehicle speed, and the friction coefficient of road surface, secondly, a cornering force of front wheels is determined in accordance with the slip angle and the friction coefficient of road surface, and thirdly, the cornering force is proportional to the operating pressure of power steering unit.

With the above-described method, in which the operating pressure of hydraulic power steering unit is used as a factor in proportion to the cornering force, the friction coefficient of road surface can be exactly detected, its detecting accuracy being increased, by taking account of the operating pressure corresponding to the cornering force of front wheels only.

The operating pressure of hydraulic power steering unit is generated quickly at the initial turning stage of vehicle, in other words, at the start of operation of steering wheel, so that the friction coefficient of road surface can be exactly detected even at the initial turning stage of vehicle.

Even though the operating angle of steering wheel is equal, the increasing and decreasing characteristics of operating pressure of hydraulic power steering unit differs greatly between the turning and turning back operations of steering wheel. For this reason, if the friction coefficient of road surface is calculated at all times when the steering wheel is operated, a large error may be produced in the detected friction coefficient of road surface. According to the present invention, the friction coefficient of road surface is calculated only when the operating angle of steering wheel increases or is held at a predetermined angular position during the operation of steering wheel, so that a stable and reliable friction coefficient of surface road can be calculated.

Preferably, the detected signal indicating the operating pressure of power steering unit may be filtered to compensate the advance in phase of operating pressure in relation to the operation of steering wheel. The advance in phase of operating pressure is caused by the characteristics of a steering valve in the power steering unit and the inertia effect of front wheels. The filtering of the detected signal or the operating pressure further increases the detection accuracy of friction coefficient of road surface.

The operating pressure of hydraulic power steering unit is preferably detected as the pressure difference between right and left pressure chambers in the power steering unit. If the operating pressure of power steering unit is detected in such a manner, a discrimination can be made whether or not the condition of the second step described above has been satisfied, that is, whether or not the proper steering situation has been detected, by taking account of a steering direction of the front wheels corresponding to the acting direction of operating pressure and a steering direction of the front wheels corresponding to the operating angle of steering wheel.

Since the friction coefficient of road surface in the third step is calculated only when the proper steering situation is detected, the friction coefficient of road surface is not calculated, for example, when the vehicle is slaloming and the steering phases determined on the basis of the operating pressure and the operating angle of steering wheel are opposite. As a result, there is no error in friction coefficient of road surface, and the detection accuracy is further increased.

When the absolute value of change ratio of the calculated friction coefficient of road surface is higher than a predetermined value, it is desirable that the calculated friction coefficient of road surface should not be set as a new friction coefficient. This prevents a sudden change of the detected friction coefficient of road surface, thus providing a stable friction coefficient of road surface.

The apparatus for detecting a friction coefficient of the road surface is an apparatus for carrying out the above-described method. The apparatus has advantages similar to those of the detecting method.

The second object of the present invention described above is achieved by a four-wheel steering method of vehicle according to the present invention, the four-wheel steering method comprising:

a first step of detecting each of an operating angle of the steering wheel, a vehicle speed and an operating pressure of a hydraulic power steering unit for the front wheels,

a second step of detecting a proper steering situation in which a condition of increase in the steering angle of front wheels is satisfied during the operating of steering wheel,

a third step of calculating a friction coefficient of the road surface on the basis of the data detected in the first step only when the proper steering situation is detected, and

a fourth step of calculating an equiphase steering angle of rear wheels to steer the rear wheels to the same direction as the steering direction of front wheels, on the basis of the rotating angle of steering wheel and the friction coefficient of road surface obtained in the third step, the equiphase steering angle of rear wheels calculated in the fourth step being increased by a predetermined increment as the friction coefficient of road surface calculated in the third step decreases.

With the above-described four-wheel steering method, the friction coefficient of road surface can be detected accurately at the initial turning stage of vehicle, as with the above-described detecting method, so that the optimum equiphase steering angle of rear wheels can be calculated on the basis of the friction coefficient of road surface thus detected.

With the four-wheel steering method according to the present invention, the turning ability of vehicle can be fully insured even when the friction coefficient of road surface is low, since the equiphase steering angle of rear wheels is increased with the decrease in friction coefficient of road surface.

The increase in equiphase steering angle of rear wheels caused by a low friction coefficient of road surface should be preferably restricted with the increase in vehicle speed. This restriction permits the optimum correction of equiphase steering angle of rear wheels in accordance with the decrease in friction coefficient of road surface when the vehicle is running at either a medium or a high speed, resulting in higher steering stability of vehicle.

It is also preferable to calculate the steering angle of rear wheels by taking account of an opposite phase steering angle for steering the rear wheels in the direction opposite to the steering of front wheels in addition to the equiphase steering angle described above. This opposite phase steering angle is calculated in accordance with the angular velocity of steering wheel. In calculating the opposite phase steering angle, it is desirable that the opposite phase steering angle be increased as the friction coefficient of road surface decreases. If the opposite phase steering angle is calculated in this way, the turning ability of vehicle front is further improved during the turning of vehicle even when the road surface has a low friction coefficient.

The four-wheel steering system of vehicle is a system for implementing the above-described steering method, and has advantages similar to those of the four-wheel steering method.

Other features and objects of the present invention will become more apparent from the following description of preferred embodiments with reference to accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a four-wheel steering system according to the present invention;
Fig. 2 is a block diagram showing a configuration of the controller in Fig. 1;
Fig. 3 is a block diagram showing a detection circuit for detecting road surface μ in Fig. 2;
Fig. 4 is a graph showing a relationship between the steering angle of front wheels and the operating pressure of power steering unit for front wheels;
Fig. 5 is a schematic view showing a cornering force occurring on the front wheels in relation to the slip angle of front wheels;
Fig. 6 is a graph showing relationships between the cornering force and the slip angle of front wheels for road surfaces having a different friction coefficient;
Figs. 7 and 8 are flowcharts showing a routine for calculating road surface μ ;
Fig. 9 is a graph showing coefficient K μ as a function of the vehicle speed;
Fig. 10 is a block diagram showing the function of control circuit for a rear steering valve of Fig. 1;
Fig. 11 is a graph showing an equiphase coefficient for the steering angle of rear wheels as a function of the vehicle speed; function of the vehicle speed;
Fig. 12 is a graph showing the opposite phase coefficient for the steering angle of rear wheels as a function of the vehicle speed; and
Fig. 13 is a graph showing a difference in steering angle of rear wheels between on a high μ road and on a low μ road.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 1, which schematically shows a four-wheel steering system of vehicle, the left front wheel FW_L and the right front wheel FW_R of the vehicle are steered by means of a power steering unit 1. More specifically, the power steering unit 1 is equipped with a front steering actuator 3 having a hydraulic cylinder, and both piston rods of the front steering actuator 3 are connected to the left front wheel FW_L and the right front wheel FW_R via a tie rod 2.

The front steering actuator 3 incorporates a rack and pinion mechanism (not shown) which is connected to a steering wheel 4, and its rack is formed as one piston rod of the front steering actuator 3. Therefore, when the steering wheel 4 is operated, the front steering actuator 3 is driven via the rack and pinion mechanism.

The front steering actuator 3 is in fluid communication with a front steering valve 5. The front steering valve 5 is mechanically connected to the steering wheel 4 . Therefore, the front steering valve 5 can be operated by the steering wheel 4.

The front steering valve 5 is connected to one hydraulic pump 7 in a pump unit 6. That is, the pump unit 6 has a pair of hydraulic pumps 7, 9 which are tandem connected with each other. These hydraulic pumps are driven by a vehicle engine 8.

The other hydraulic pump 9 is connected to a rear steering actuator 11 via a rear steering valve 10. This rear steering actuator 11 includes a hydraulic cylinder similar to that in the above-mentioned front steering actuator 3. Both piston rods of the rear steering actuator 11 are connected to the left rear wheel RW_L and the right rear wheel RW_R via a tie rod 12. The suction ports of hydraulic pumps 7, 9 are connected to a reservoir tank 14.

When the steering wheel 4 is operated, the hydraulic fluid is fed from the hydraulic pump 7 to the front steering actuator 3 by the changeover of the front steering valve 5. As a result, the front steering actuator 3 operates in accordance with the rotational direction of steering wheel 4; thus, the front wheels FW are steered.

When the front wheels FW are steered, the rear wheels RW can also be steered via the rear steering valve 10 and the rear steering actuator 11. Since the rear steering valve 10 is electrically connected to a controller 15 as shown in Fig. 1, the controller 15 supplies a control signal S_R to the rear steering valve 10 in accordance with the running condition of vehicle to control the changeover of the rear steering valve 10. As a result, the pressure and feeding direction of hydraulic fluid, which is fed from the hydraulic pump 9 to the rear steering actuator 11 via the rear steering valve 10, is controlled, and then the rear wheels RW_L and RW_R are steered.

The controller 15 is also electrically connected to the front steering valve 5, so that the front steering valve 5 can receive a control signal S_F from the controller 15. When the control signal S_F is sent from the controller 15 to the front steering valve 5, the front steering valve 5 controls the feed pressure of hydraulic fluid to the front steering actuator 3 so as to advance the steering phase of front wheels FW in relation to the operation of steering wheel 4.

For the controller 15 to produce control signals S_F, S_R which are to be fed to the steering valves 5, 10, the controller 15 is electrically connected to various sensors and meters. The meters supply detection signals indicating the operating conditions of various devices to the controller 15.

The above-mentioned sensors include a vehicle speed sensor 26 for detecting the vehicle speed, a sensor 16 for detecting the operating angle θ_H of steering wheel 4, a sensor 17 for detecting the actual steering angle δ_{Ra} of rear wheels RW, and a sensor for detecting the operating pressure of front steering actuator 3. Sensor signals from these sensors are fed to the controller 15.

In this embodiment, the sensor for detecting the operating pressure of front steering actuator 3 includes a pair of pressure sensors 18, 19. These pressure sensors 18, 19 detect the pressures in a right and left pressure chambers (not shown) in the front steering actuator 3, respectively, to send their sensor signals to the controller 15. The controller 15 calculates the pressure difference between the two pressure chambers on the basis of the sensor signals from a pair of pressure sensors 18, 19, and this pressure difference is used as the operating pressure ΔP of front steering actuator 3.

A typical internal circuit of controller 15 is shown in Fig. 2. The controller 15 has an input circuit 30 which receives the sensor signals indicating the operating angle θ_H of steering wheel 4, the vehicle speed V, and the actual steering angle δ_{Ra} of rear wheels RW from the sensors 16, 26, 17, respectively, and an analog/digital (A/D) converter 31 which receives the sensor signals indicating the pressures P_L, P_R in the pressure chambers of front steering actuator 3 detected by the pressure sensors 18, 19, respectively. The input circuit 30 is connected to a decision circuit 32, which selects one steering control mode of the vehicle from a number of modes on the basis of the data supplied through the input circuit 30, namely, the data indicating the operating angle θ_H, the vehicle speed V, and the actual steering angle δ_{Ra} of rear wheels RW, and the detection data from the meters. These steering control modes include an interruption mode of the steering control, an-opposite phase steering mode of the rear wheels RW in which the rear wheels RW are steered in the opposite phase with the front wheels FW when the vehicle speed is low and the operating angle θ_H is large (for example, $V \leqq 30$km/h and $\theta_H \geqq 230°$), and a phase control mode in which the steering phases of front and rear wheels are controlled when the vehicle speed is in the medium and high speed range (for example, $V \geqq 40$km/h).

The input circuit 30 and the A/D converter 31 are connected to a detection circuit 33 for detecting the friction coefficient of road surface, namely the road surface μ. The detection circuit 33, to which the data indicating the operating angle θ_H and the vehicle speed V are supplied from the input circuit 30 and the data indicating the pressures P_L, P_R are supplied from the A/D converter 31, determines the road surface μ by calculating it on the basis of these data.

The decision circuit 32 and the detection circuit 33 are connected to a control circuit 34 for the front and rear steering valves 5, 10. This control circuit 34 receives the steering control mode selected by the decision circuit 32 and the data indicating the road surface μ determined by the detection circuit 33. As seen from Fig. 2, the control circuit 34 also receives the data indicating the operating angle θ_H, the vehicle speed V and the actual steering angle δ_{Ra} supplied from the input circuit 30. On the basis of these supplied data, the control circuit 34 produces the above-mentioned control signals S_F, S_R. These signals S_F, S_R are fed from the control circuit 34 to the front and rear steering valves 5, 10, respectively, via an output circuit 35.

The specific procedure for calculating the road surface μ in the detection circuit 33 is shown in the block diagram of Fig. 3. As seen from Figure 3, an arithmetic section 20 for road surface μ receives the operating pressure ΔP of front steering actuator 3, obtained from the pressures P_L, P_R detected by the pressure sensors 18, 19, the operating angle θ_H detected by the sensor 16, and the vehicle speed V detected by the sensor 26. The operating pressure ΔP is calculated in a subtraction section 22 to which pressures P_L, P_R are supplied, and then sent to the arithmetic section 20 through a filter 21 for phase compensation. The filter 21 serves two functions; it not only removes noise of operating pressure ΔP but also compensates the advance of phase of operating pressure ΔP in relation to the operating angle θ_H at the transition stage for the operation of steering wheel 4. At the start of the operation of steering wheel 4, the operating pressure ΔP of front steering actuator 3 increases suddenly as shown by the solid line in Fig. 4, and at the start of turning back of steering wheel 4, the operating pressure ΔP decreases suddenly. This means that a phase difference occurs in the change tendency of the operating angle θ_H and the operating pressure ΔP. However, the phase difference between the operating angle θ_H and the operating pressure ΔP is compensated in the filter 21, so that the operating pressure ΔP increases and decreases with the change in the operating angle θ_H as shown by the broken line in Fig. 4.

The phase difference between the operating angle θ_H and the operating pressure ΔP is produced by the operating characteristics of front steering valve 5 itself and the tire inertia effect.

In the arithmetic section 20, the road surface μ is calculated on the basis of the operating pressure ΔP, the operating angle θ_H and the vehicle speed V. The principle of calculating the road surface μ will be explained below by referring to Fig. 5.

When the front wheels FW are steered, the cornering force C_F of the right front wheel FW_R is expressed by the following equation:

$$C_F \alpha \beta f \cdot \mu$$

where, βf is an inclination angle or a slip angle of right front wheel FW_R in relation to the traveling direction of right front wheel FW_R as shown in Fig. 5.

As seen from the above equation, the cornering force C_F is proportional to the product of slip angle βf and road surface μ. Therefore, if the road surface μ is different, that is, the condition of road surface is different, the cornering force C_F of front wheel differs greatly even if the slip angle βf is equal. Specifically, the cornering force C_F of front wheel increases as the road surface μ increases, in the range where the slip angle βf is large as shown in Fig. 6. In Figure 5, reference symbol L denotes the line in parallel with the vehicle body axis, and reference symbol δ_F denotes the steering angle of right front wheel FW_R, namely the front wheels FW.

As seen from Fig. 5, considering the dynamic equilibrium condition, the cornering force C_F and the operating pressure ΔP of front steering actuator 3 are in a nearly proportional relationship. Therefore, using the operating pressure ΔP in place of the cornering force C_F, the above equation can be rewritten as follows:

$$\Delta P = C_1 \cdot \beta f \cdot \mu \quad (1)$$

where, C_1 is a constant.

The slip angle βf is expressed by the following equation as a function of vehicle speed V, operating angle θ_H, and road surface μ.

$$\beta f = C_3 \cdot V^2 \cdot \theta_H/(\mu + C_2 \cdot V^2) \quad (2)$$

where, C_2 and C_3 are constants.

From Equations (1) and (2), the ratio of the operating pressure ΔP to the operating angle θ_H, $\Delta P/\theta_H$, is expressed by the following equation:

$$\Delta P/\theta_H = \mu \cdot C_1 \cdot C_3 \cdot V^2/(\mu + C_2 \cdot V^2) \quad (3)$$

In the arithmetic section 20, therefore, the road surface μ is calculated from Equation (3) by putting the values of vehicle speed V, operating angle θ_H and operating pressure ΔP into Equation (3).

The calculated road surface μ is output through a limit section 23 and a stabilizing filter 24. The limit section 23 supplies the road surface μ as it is to the stabilizing filter 24 if the change rate of road surface μ supplied from the arithmetic section 20 is within the allowable range, but stops the output of road surface μ to the stabilizing filter if the change rate of road surface μ is outside the above allowable range. The limit section 23 may output the road surface μ obtained by limiting its change rate to the maximum or minimum value to the stabilizing filter 24 if the change rate of road surface μ is outside the above allowable range. The stabilizing filter 24 serves a function of stabilizing and outputting the value of road surface μ supplied from the limit section 23.

The above-described calculating procedure for the road surface μ shown by the block diagram in Fig. 3 becomes apparent upon making reference to the calculation routine for road surface μ shown by a flowchart in Figs. 7 and 8. Therefore, the calculation routine will be explained below.

Calculation routine for road surface μ

First, in Step S1 in Fig. 7, the operating angle θ_H, pressures P_L, P_R and vehicle speed V detected by the sensors 16, 18, 19 and 26, are read.

Next, in Step S2, the pressure difference between the pressures P_L and P_R, namely the operating pressure ΔP (= P_R - P_L) of front steering actuator 3 is calculated. Then, the operating pressure ΔP is filtered in the above-mentioned filter 21 for phase compensation in Step S3.

In Step S4, a decision is made on whether the steering wheel 4 is being operated or held at a rotational angle position or not. This decision is made on the basis of the magnitude and change direction of operating angle θ_H of steering wheel 4.

When the decision result in Step S4 is NO, namely when the steering wheel 4 is turned back, the flow returns to Step S1 and the above steps are repeated as shown in the flowchart of Fig. 8.

When the decision result in Step S4 is YES, namely when the steering wheel 4 is turned or held at a rotational angle position, the flow proceeds to Step S5.

In Step S5, a decision is made on whether the absolute value of the operating angle θ_H of steering wheel 4 is not lower than a predetermined positive value θ_1 (for example, 10°) or not. When the decision result in this step is NO, namely the absolute value of the operating angle θ_H is smaller than the positive value θ_1, it is decided that the steering wheel 4 has not yet been turned, and the flow returns from Step S5 to Step S1 so that the steps are repeated from the beginning.

When the decision result in Step S5 is YES, namely the absolute value of the operating angle θ_H is not lower than the positive value θ_1, the flow proceeds to Step S6, where the ratio of the operating pressure ΔP to the operating angle θ_H, $\Delta P/\theta_H$, is calculated.

Then, the flow goes from Step S6 to Step S7 in Fig. 8, in which another decision is made. In this step, a decision is made on whether the direction in which the front wheels FW are steered by the front steering actuator 3 on the basis of the operating pressure ΔP is in agreement with the direction in which the front wheels FW are steered on the basis of the operating angle θ_H of steering wheel 4, in other words, whether the sign of $\Delta P/\theta_H$ is plus or not. When the decision result is NO, it is determined that the vehicle is slaloming and the steering wheel 4 is being operated by repeating turning and back turning, or that the phase of change of operating pressure ΔP is opposite to that of the operating angle θ_H in spite of the filtering in Step S3. In this case, the flow returns from Step S7 to Step S1 so that the steps are repeated from the beginning.

When the decision result in Step S7 is YES, the flow goes to Step S8, in which a coefficient $K\mu$ used for calculating the road surface μ is determined. Specifically, the coefficient $K\mu$ is read from a map that represents the coefficient $K\mu$ as a function of the vehicle speed V as shown in Fig. 9. This map has been stored in advance in memory (not shown) in the detection circuit 33 in Fig. 2.

The coefficient $K\mu$ is equivalent to the equation in brackets [ ] in the following equation, which is obtained by rewriting Equation (3).

$$\mu = [1 + C_2 \cdot V^2/(C_1 \cdot C_3 \cdot V^2)] \cdot \Delta P/\theta_H \quad (4)$$

Therefore, the coefficient $K\mu$ can be expressed by the following equation:

$$K\mu = 1 + C_2 \cdot V^2/(C_1 \cdot C_3 \cdot V^2) \quad (5)$$

Therefore, the map in Fig. 9 can be represented as a function of the vehicle speed V as seen from Equation (5).

In Step S9, the value of coefficient $K\mu$ read in Step S8 is multiplied by the value of $\Delta P/\theta_H$ determined in Step S7 in Fig. 7 to calculate the road surface μ. That is, the road surface μ can be calculated by putting the value of $\Delta P/\theta_H$ and the value of vehicle speed V into Equation (4).

In Step S10, a decision is made on whether the absolute value of change rate for the calculated road surface μ, namely the absolute value of the differentiation result of road surface μ (= $d\mu/dt$) is within a predetermined value $\Delta\mu$ (for example, 0.2 μ/sec) or not. When the decision result is NO, the flow returns to Step S1. On the other hand, when the result is YES, filtering is carried out to stabilize the value of the calculated road surface μ in Step S11, and then the road surface μ is finally output in Step S12.

According to the above-described embodiment, the road surface μ is detected each time the steering wheel 4 is operated on running the vehicle. Therefore, the steering angle δ_R of rear wheels RW can be controlled on the basis of the latest value of road surface μ. Even if the road surface condition changes, the road surface μ is detected at the time when the steering wheel 4 is operated, so that the optimum steering control of rear wheels RW is performed in accordance with the road surface condition, namely the road surface μ, resulting in some improvement in steering stability of the vehicle.

Since the operating pressure ΔP of front steering actuator 3 is calculated on the basis of the sensor signals sent from the pressure sensors 18 and 19, and then filtered for phase compensation, the advance of phase of the operating pressure ΔP in relation to the steering angle θ_H can be prevented at the operating transition stage of the steering wheel 4.

In calculating the road surface μ, an exact value of road surface μ can be obtained since the road surface μ is calculated in Step S9 only when all the decision results in Steps S4, S5 and S7 are YES. The YES decision results in Steps S4 and S5 mean that the steering wheel 4 is operated so that the absolute value of operating angle θ_H of the steering wheel 4 is not smaller than the specified value θ_1 or the steering wheel 4 is held at a predetermined rotational angle position. In this case, since the front wheels FW are steered by the front steering actuator 3, the operating pressure ΔP of the front steering actuator 3 is in the condition of actual increase. As a result, the road surface μ can be exactly calculated on the basis of the operating pressure ΔP. The YES decision result in Step S7 means that the steering direction of front wheels FW on the basis of the operating pressure ΔP is in agreement with the steering direction of front wheels FW on the basis of the operating angle θ_H. Therefore, the road surface μ can be calculated by precluding the adverse effects of the characteristics of front steering valve 5 and the inertia of front wheel FW tires. This also improves the accuracy of the calculated value of road surface μ.

When either of decision results in Steps S4, S5 or S7 is NO, a new road surface μ is not calculated since Step S8 and the subsequent steps are not performed. In this case, the previously calculated value is kept.

Further, according to the above-described embodiment, even when the road surface μ is calculated in Step S9, this calculated road surface μ is not immediately output, but is output through the executions in Steps S10 and S11. The execution in Step S10 means that the value of calculated road surface μ is changed into a new value only when the absolute value of road surface μ is within the specified value $\Delta\mu$. Furthermore, since the road surface μ is finally output through the filtering operation for stabilization, a sudden change in the value of road surface μ does not occur, and a stabilized output value of road surface μ is produced.

The road surface μ calculated by the above-described routine is supplied from the detection circuit 31 to the control circuit 34 for controlling the steering valves. In this control circuit 34, the steering angle δ_R of rear wheels RW is calculated from the road surface μ, the operating angle θ_H and the vehicle speed V as described above. The procedure for calculating the steering angle δ_R in the control circuit 34 is shown by the block diagram in Fig. 10.

For explanation by referring to the block diagram in Fig. 10, it is assumed that the phase control mode has been selected in the decision circuit 32 in Fig. 2. This block diagram, being for calculating the steering angle δ_R of rear wheels RW, does not indicate the control for advancing the steering phase of front wheels FW in relation to the operating angle θ_H of steering wheel 4.

First, the operating angle θ_H of steering wheel 4 is supplied to an amplification section 40, where a steering angle δ_1 of the rear wheels RW is calculated by multiplying the operating angle θ_H by (K_1/ρ). This steering angle δ_1 represents the steering amount for steering the rear wheels RW to the same direction as the steering direction of front wheels FW, namely in the same phase. K_1 is the so-called equiphase coefficient, and ρ is the steering gear ratio.

The operating angle θ_H is also supplied to a differentiation section 41, where the angular velocity $\Delta\theta_H$ of steering wheel 4 is calculated. Then, the calculated angular velocity $\Delta\theta_H$ is multiplied by (K_2/ρ), so that a steering angle δ_2 of rear wheels RW is calculated, in another amplification section 42. The steering angle δ_2 represents the steering amount for steering the rear wheels RW in the direction opposite to the steering direction of front wheels FW, namely in the opposite phase. Therefore, K_2 represents the opposite phase coefficient.

The steering angle δ_2 of opposite phase is then supplied to a limit section 43. This limit section 43 outputs the steering angle δ_2 when the absolute value of steering angle δ_2 is not smaller than a predetermined value (for example, 0.03°), but it sets the steering angle δ_2 at 0° and outputs it when the absolute value of steering angle δ_2 is smaller than the predetermined value.

The steering angles δ_1, δ_2 of rear wheels RW calculated in the multiplication section 40 and the limit section 43 are supplied to a subtraction section 44, where the steering angle δ_R of rear wheels RW is calculated by subtracting the steering angle δ_2 from the steering angle δ_1.

Summarization of the above-described calculation procedure for the steering angle δ_R of rear wheels RW, namely the calculation procedure carried out in sections 40 through 42, gives the following equation:

$$\delta_R = \delta_1 - \delta_2 = \theta_H \cdot (K_1/\rho) - \Delta\theta_H \cdot (K_2/\rho) \quad (6)$$

Then, in the control circuit 34 of Fig. 2, the difference between the steering angle δ_R calculated as described above and the actual steering angle δ_{Ra} of rear wheels RW is calculated. The control signal S_R based on this difference is sent from the control circuit 34 to the rear steering valve 10 via the output circuit 35. When the rear steering valve 10 receives the control signal S_R, the rear steering valve 10 controls the operating pressure supplied to the rear steering actuator 11 and the supply direction of the operating pressure. Thus, the rear steering actuator 11 operates to match the actual steering angle δ_{Ra} of rear wheels RW to the steering angle δ_R.

The above-mentioned equiphase coefficient K_1 and opposite phase coefficient K_2 are usually determined on the basis of the vehicle speed V. In this embodiment, however, the equiphase coefficient K_1 and opposite phase coefficient K_2 are determined by considering the detected road surface μ in addition to the vehicle speed V.

As seen from Fig. 10, the detected road surface μ is supplied to an arithmetic section 45, to which the vehicle speed V is also supplied after being filtered in a filter section 46. In the arithmetic section 45, the corrected vehicle speed V' is calculated by the following equation:

$$V' = V + (1-\mu) \cdot K_V \quad (7)$$

where, K_V is a standard value for correcting the vehicle speed V, which is set at 20km/h, for example

The corrected vehicle speed V' calculated by Equation (7) is supplied to another arithmetic section 47, where the equiphase coefficient K_1 is calculated from the corrected vehicle speed V'. Specifically, in this embodiment the equiphase coefficient K_1 can be determined as a function of the corrected vehicle speed V' as indicated by the solid line in Fig. 11.

As shown by the solid line in Fig. 11, the equiphase coefficient K_1 begins increasing as the corrected vehicle speed V' increases from the medium speed range (for example, about 60km/h), and levels off when the corrected vehicle speed V' reaches the high speed range.

The solid line in Fig. 11 indicates the feature of the equiphase coefficient K_1 for high road surface μ, namely in the case where the road surface has a high μ value. The solid line map in Fig. 11 is stored in advance in memory (not shown) in the control circuit 34 in Fig. 2.

As seen from the above equation for calculating the corrected vehicle speed V' and the map in Fig. 11, the value of the second term of the equation (7), $(1-\mu) \cdot K_V$, increases as the value of road surface μ decreases. Therefore, the corrected vehicle speed V' is further higher than the actual vehicle speed V as the road surface μ decreases. This means that in Fig. 11, the characteristic curve indicated by the solid line shifts to the left in the direction of the horizontal axis of the figure as shown by the broken line as the road surface μ decreases. As a result, when the road surface μ is low and the vehicle speed is in the medium speed range, the equiphase coefficient K_1 is increased in accordance with the decrease in road surface μ. The equiphase coefficient K_1 determined this way in the arithmetic section 47 is supplied to the above-mentioned amplification section 40 and used in calculating the steering angle δ_1.

The vehicle speed V is also supplied to an arithmetic section 48 after being filtered in the filter section 46. In the arithmetic section 48, the opposite phase coefficient K_2 is calculated. Specifically, the opposite phase coefficient K_2 is determined from the vehicle speed V in accordance with the map in Fig. 12. As seen from the solid line in Fig. 12, the opposite phase coefficient K_2 reaches its maximum value when the vehicle speed V is in a relatively low speed range, for example, the vehicle speed V is about 30km/h, and decreases when the vehicle speed V decreases or increases from the speed of about 30km/h. The solid line in Fig. 12, like that in Fig. 11, indicates the feature for high road surface μ. The map in Fig. 12 is also stored in memory in the control circuit 34 in Fig. 2.

The opposite phase coefficient K_2 determined in the arithmetic section 48 is then supplied to an arithmetic section 49, where the opposite phase coefficient K_2 is corrected. Specifically, the opposite phase coefficient K_2 is corrected on the basis of the road surface μ by using the following equation:

$$K_2 = K_2 \cdot (a - b \cdot \mu) \quad (8)$$

where, a and b are constants.

As shown by Equation (8), when the road surface μ decreases, the opposite phase coefficient K_2 is increased in accordance with the decrease in road surface μ. This means that the feature shown by the solid line changes into the feature shown by the broken line in Fig. 12.

The opposite phase coefficient K_2 corrected in the arithmetic section 49 is supplied to the above-mentioned amplification section 42 and used for calculating the opposite phase steering angle δ_2.

As described above, if the vehicle speed V' is corrected in accordance with the value of road surface the corrected vehicle speed V' calculated by Equation (7) increases when the road surface μ is low. Thus, the equiphase coefficient K_1 increases when the road surface μ is low and the vehicle speed V is in the medium speed range, namely when the vehicle is running at a speed in the medium speed range on a road with a low μ as shown by the broken line in Fig. 11. In this case, the equiphase steering angle δ_1 of rear wheels RW increases, therefore, the amount of steering to the equiphase side, contained in the steering angle δ_R of rear wheels RW in relation to the steering of front wheels FW, increases as shown in Equation (6). Consequently, when the front wheels FW are steered on running at a speed in the medium speed range on a road with a low μ, the amount of steering of the rear wheels RW in the equiphase with the front wheels FW increases, so that the spinning of vehicle is effectively prevented and the steering stability of vehicle is improved.

When the vehicle speed V is in the high speed range, the equiphase coefficient K_1 is not increased even when the road surface μ is low and the corrected vehicle speed V' increases in accordance with Equation (7), as seen from the above explanation. Therefore, the amount of steering of the rear wheels RW in the equiphase with the front wheels FW does not further increase when the front wheels FW is steered. This means that the amount of steering of the rear wheels RW in the equiphase does not increase when the front wheels FW is steered, even if the corrected vehicle speed V' is in the high speed range in the condition where it has been decided that the road has a low μ though it has really a high μ due to an error in detecting the road surface μ. Consequently, undesirable and excessive steering of the rear wheels RW in the equiphase with the front wheels FW is prevented in the above-described condition, providing fail-safe steering.

The opposite phase coefficient K_2 is corrected so as to be increased as shown by the broken line in Fig. 12 and as seen from Equation (8) when the vehicle speed V is in a relatively low speed range and the road surface μ is low. In this case, the opposite phase steering angle δ_2 in Equation (6), namely the amount of steering of the rear wheels RW in the direction opposite to the steering direction of front wheels FW increases when the change rate of operating angle θ_H at the steering wheel 4, namely the angular velocity $\Delta\theta_H$ is increased by the relatively rapid operation of steering wheel 4. This means that in the change characteristics of steering angle δ_R of the rear wheels RW shown in Fig. 13, the amount of instantaneous steering of rear wheels RW in the opposite phase in the area encircled by the alternate long and two short dashes line increases. Consequently, when the steering wheel 4 is operated while the vehicle is running at a relatively low speed on a road with a low μ, the turning ability of the vehicle is improved, assuring high steering stability on roads with a low μ.

The above-described steering control method for the rear wheels, needless to say, improves the delay in response to the lateral acceleration and yawing acting on the vehicle in relation to the operation of steering wheel 4.

The control for advancing the phase of steering angle δ_F of the front wheels FW in relation to the operating angle θ_H of steering wheel 4 will be briefly explained below. This control is to increase the steering angle δ_F of front wheels FW in accordance with the angular velocity $\Delta\theta_H$ of steering wheel 4. To do this, the steering angle δ_F of the front wheels FW is calculated by adding $\Delta\theta_H \cdot K_3/\rho$ to the value obtained from the operating angle θ_H of steering wheel 4, and the control signal S_F on the basis of the calculated steering angle δ_F is fed to the front steering valve 5.

K_3 is a coefficient for advancing the phase. It varies with the vehicle speed V, like the opposite phase coefficient K_2 in Fig. 12, and also varies with the value of road surface μ, like the opposite phase coefficient K_2. If the phase of steering angle δ_F of the front wheels FW is advanced in the above-described manner, the response to yawing acting on the vehicle body while the vehicle is turning can be further improved.

This invention is not limited to the abovedescribed embodiment, but can be carried out in many variations. For example, though the operating pressure ΔP of front steering actuator 3 is calculated from the sensor signals from a pair of pressure sensors 18 and 19 in the above-described embodiment, the operating pressure ΔP can be determined by a single pressure sensor in place of the pressure sensors 18 and 19. In this case, a pressure sensor 25 is disposed near the discharge port of hydraulic pump 7 as shown in Fig. 1. The pressure sensor 25 detects the discharge pressure of hydraulic pump 7. The discharge pressure P_S of hydraulic pump 7 is supplied to the filter 21 for phase compensation as shown in the block diagram in Fig. 3. In Step S1 in Fig. 7, the discharge pressure P_S is read in place of the pressures P_L and P_R, and Step S7 in the flowchart in Fig. 8 is bypassed as shown by the broken line.

In the flowchart in Fig. 7, Step S4 may decide on only whether the steering wheel 4 is operated or not. In this case, the road surface μ is not calculated when the steering wheel 4 is held at the specified rotational position or it is turned back.

Although the coefficients K_1, K_2 and K_3 are corrected so as to be increased as the road surface μ decreases, they may be corrected so that only the equiphase coefficient K_1 is increased with decreasing road surface μ . In carrying out this invention, the above-described control for advancing the steering phase of front wheels FW is not necessarily needed.

It is to be understood that the present invention is not limited to the above-described embodiments, and that various changes and modifications may be made in the invention without departing from the spirit and the scope of the invention as hereinafter claimed.

Claims

1. A method for detecting a friction coefficient of road surface on which a vehicle runs, the vehicle having front wheels (FW), a steering wheel (4), and a hydraulic power steering unit (1) disposed between the front wheels and the steering wheel, the hydraulic power steering unit assisting the steering wheel in steering the front wheel, and the method comprising a detection step of detecting an operating angle (θ_H) of the steering wheel and a vehicle speed (V), and a calculation step of calculating a friction coefficient (μ) of the road surface on the basis of the detected operating angle and the vehicle speed,

   characterized in that

   said calculation step includes;

   a first step of detecting an operating pressure (ΔP) of the hydraulic power steering unit;

   a second step of detecting a proper steering situation in which a condition of increase in the steering angle of the front wheels is satisfied when the steering wheel is operated; and

   a third step of calculating the friction coefficient of the road surface on the basis of the data detected in said first step only when the proper steering situation is detected, the friction coefficient of the road surface being calculated by using relationships of three conditions;

   (a) a slip angle (βf) of the front wheels is determined in accordance with the operating angle of the steering wheel, the vehicle speed and the friction coefficient of the road surface,

   (b) a cornering force (C_F) of the front wheels is determined in accordance with the slip angle and the friction coefficient of the road surface, and

   (c) the cornering force is proportional to the operating pressure of the hydraulic power steering unit.

2. The method according to claim 1, characterized in that said second step, when a condition that the absolute value of the operating angle of the steering wheel is not smaller than a predetermined value (θ_1) is satisfied in addition to said condition, this situation is detected as the proper steering situation.

3. The method according to claim 1, characterized in that said first step includes a filtering process (21) for compensating a phase advance of the operating pressure in relation to the operating angle of the steering wheel.

4. The method according to claim 1, characterized in that the hydraulic power steering unit has right and left pressure chambers, and a pressure difference (ΔP) between the right and left pressure chambers is detected as the operating pressure of the hydraulic power steering unit.

5. The method according to claim 4, characterized in that in said second step, when a condition that a steering direction of the front wheels on the basis of a direction in which the operating pressure occurs is in agreement with a steering direction of the front wheels on the basis of the operating angle of the steering wheel is satisfied in addition to said condition, this situation is detected as the proper steering situation.

6. The method according to claim 1, characterized in that in said third step, when the operating angle of the steering wheel obtained in said first step is denoted by θ_H, the vehicle speed by V and the operating pressure of the hydraulic power steering unit by ΔP, the friction coefficient μ of the road surface is expressed as

   $$\mu = K\mu - \Delta P / \theta_H$$

   where, $K\mu$ is a coefficient expressed as

   $$K\mu = 1 + C_2 \cdot V^2/(C_1 \cdot C_2 \cdot V^2)$$

   where, C_1, C_2 and C_3 are constants.

7. The method according to claim 1, characterized in that the method further includes a fourth step executed after said third step, and said first through fourth steps are executed repeatedly, said fourth step including a process of calculating a change rate ($d \mu /dt$) of the friction coefficient of the road surface on the basis of the friction coefficient determined in said third step, and a process of outputting the friction coefficient of the road surface calculated in the last third step as it is when the absolute value of the calculated change rate of the friction coefficient is not larger than a predetermined value, and keeping and outputting the friction coefficient of the road surface calculated in the previous third step when the absolute value of it is larger than the predetermined value.

8. The method according to claim 1, characterized in that the method further includes a fifth step, in which filtering (24) is performed to stabilize the calculated friction coefficient of the road surface.

9. The method according to claim 1, characterized in that the hydraulic power steering unit includes a steering actuator (3) disposed between the front wheels and the steering wheel, a hydraulic pump (7) for supplying hydraulic fluid to the steering actuator and a front steering valve (5) disposed between the hydraulic pump and the steering actuator for controlling a flow direction of the hydraulic fluid from the hydraulic pump to the steering actuator, and in said first step, the operating pressure of the hydraulic power steering unit is detected on the basis of the fluid pressure between the front steering valve and the hydraulic pump.

10. The method according to claim 1, characterized in that in said second step, when either said condition or a condition that the steering wheel is held at an angular position beyond a predetermined angular position is satisfied, this situation is detected as the proper steering situation.

11. An apparatus for detecting a friction coefficient of a road surface on which the vehicle is running, the vehicle having front wheels (FW), a steering wheel (4), and a hydraulic power steering unit (1) disposed between the front wheels and the steering wheel, the hydraulic power steering unit assisting the steering wheel in steering the front wheels, and the apparatus comprising means (16) for detecting an operating angle (θ_H) of the steering wheel, means (26) for detecting a vehicle speed (V), and means (15) for obtaining the friction coefficient (μ) of the road surface on the basis of the operating angle of steering wheel and vehicle speed detected by the said means,

characterized in that

said means (15) comprises means (18,19) for detecting an operating pressure (ΔP) of the power steering unit as a factor in proportion to a cornering force of the front wheels and calculation means for calculating the friction coefficient of the road surface on the basis of the operating angle of the steering wheel, the vehicle speed and the operating pressure detected by said means,

said calculation means including means for detecting a proper steering situation in which a condition of increase in the steering angle of the front wheels is satisfied when the steering wheel is operated, and means for calculating the friction coefficient of the road surface by using relationships of three conditions;

(a) a slip angle (βf) of the front wheels is determined in accordance with the operating angle of the steering wheel, the vehicle speed and the friction coefficient of the road surface,

(b) a cornering force (C_F) of the front wheels is determined in accordance with the slip angle and the friction coefficient of the road surface, and

(c) the cornering force is proportional to the operating pressure of the hydraulic power steering unit.

12. A four-wheel steering method of a vehicle, the vehicle having a steering wheel (4), front wheels (FW) steered by the steering wheel, a hydraulic power steering unit (1) disposed between the front wheels and the steering wheel, the hydraulic power steering unit assisting the steering wheel in steering the front wheels, and rear wheels (RW) which can be steered in accordance with the steering of the front wheels, and said method comprising a step of detecting an operating angle (θ_H) of the steering wheel and a speed (V) of the vehicle and a calculation step of calculating a steering angle (δ_R) of the rear wheels on the basis of the detected operating angle and vehicle speed,

characterized in that

said calculation step comprises a first step of detecting an operating pressure (ΔP) of the hydraulic power steering unit, a second step of detecting a proper steering situation in which a condition of increase in the steering angle of the front wheels is satisfied when the steering wheel is operated, a third step of calculating a friction coefficient (μ) of the road surface on the basis of the data detected in said first step only when the proper steering situation is detected, and a fourth step of calculating an equiphase steering angle (δ_1) of the rear wheels for steering the rear wheels in the same direction as the steering direction of the front wheels on the basis of the operating angle of the steering wheel and the friction coefficient of the road surface determined in said third step when the front wheels are steered, the equiphase steering angle of the rear wheels calculated in said fourth step being increased by a predetermined amount as the friction coefficient of the road surface calculated in said third step decreases.

13. The method according to claim 12, characterized in that in said fourth step, a increasing amount of the equiphase steering angle of the rear wheels is decreased with increasing vehicle speed.

14. The method according to claim 13, characterized in that said fourth step includes a process for preparing a map for reading the equiphase steering angle of the rear wheels, the map indicating an equiphase coefficient (K_1) in accordance with the vehicle speed, and the equiphase coefficient increasing from zero as the vehicle speed increases from a predetermined speed and leveling off at a predetermined value, and wherein said fourth step further includes a process of correcting the vehicle speed used for reading the equiphase coefficient so that the vehicle speed increases with the decrease in the calculated friction coefficient of the road surface, and a process of multiplying the operating angle of the steering wheel by the equiphase coefficient read from the map in accordance with the corrected vehicle speed and then calculating the equiphase steering angle of the rear wheels from the multiplication result.

15. The method according to claim 12, characterized in that said fourth step includes a first process of calculating an opposite phase steering angle (δ_2) of the rear wheels in the direction opposite to the steering direction of the front wheel on the basis of an angular velocity (Δ_H) obtained from the operating angle of the steering wheel and the friction coefficient of the road surface, the opposite phase steering angle thus calculated being increased with the decrease in friction coefficient of the road surface, and a second process of finally calculating the steering angle of the rear wheels by adding the opposite phase steering angle to the equiphase steering angle of the rear wheels.

16. The method according to claim 15, characterized in that said fourth step further includes a third process executed between the first and second processes, and in the third process, the opposite phase steering angle is set at zero when the calculated opposite phase steering angle does not reach a predetermined value.

17. The method according to claim 15, characterized in that the first process is a process for preparing a map for reading the opposite phase steering angle of the rear wheels, the map indicating an opposite phase coefficient (K_2) in accordance with the vehicle speed, the opposite phase coefficient being increased gradually and then decreased gradually as the vehicle speed increases, and wherein the first process further includes a process of correcting the opposite phase coefficient so that it increases with the decrease in the calculated friction coefficient of the road surface, and a process of calculating the opposite phase steering angle of the rear wheels on the basis of the angular velocity of the steering wheel and the corrected opposite phase coefficient.

18. The method according to claim 15, characterized in that the method further includes a process of increasing the steering angle of the rear wheels by a predetermined amount in accordance with the angular velocity of the steering wheel, the predetermined amount is increased with the decrease in the calculated friction coefficient of the road surface.

19. A four-wheel steering system of a vehicle having front and rear wheels, comprising a steering wheel (4) for steering the front wheels, a hydraulic power steering unit (1) disposed between the front wheels and the steering wheel, means (16) for detecting an operating angle (θ_H) of the steering wheel, means for detecting a vehicle speed (V), and rear steering means for steering the rear wheels in accordance with the operating angle of the steering wheel when the front wheels are steered,

characterized in that the system further includes means (18,19) for detecting an operating pressure of the hydraulic power steering unit, and said rear steering means includes means for determining an equiphase steering angle (δ_1) of the rear wheels to steering the rear wheels in the same direction as the steering direction of the front wheels on the basis of the operating angle of the steering wheel when the steering wheel is operated, means for deciding on whether a condition that the steering wheel is being operated and the steering angle of the front wheels are increasing is satisfied or not, on the basis of the detected operating angle of the steering wheel, a means for calculating a friction coefficient (μ) of the road surface on the basis of the detected operating angle of the steering wheel, the vehicle speed, and the operating pressure only when said condition is satisfied, and means for correcting the equiphase steering angle of the rear wheel so that it increases as the calculated friction coefficient of road surface decreases.

F I G. 1

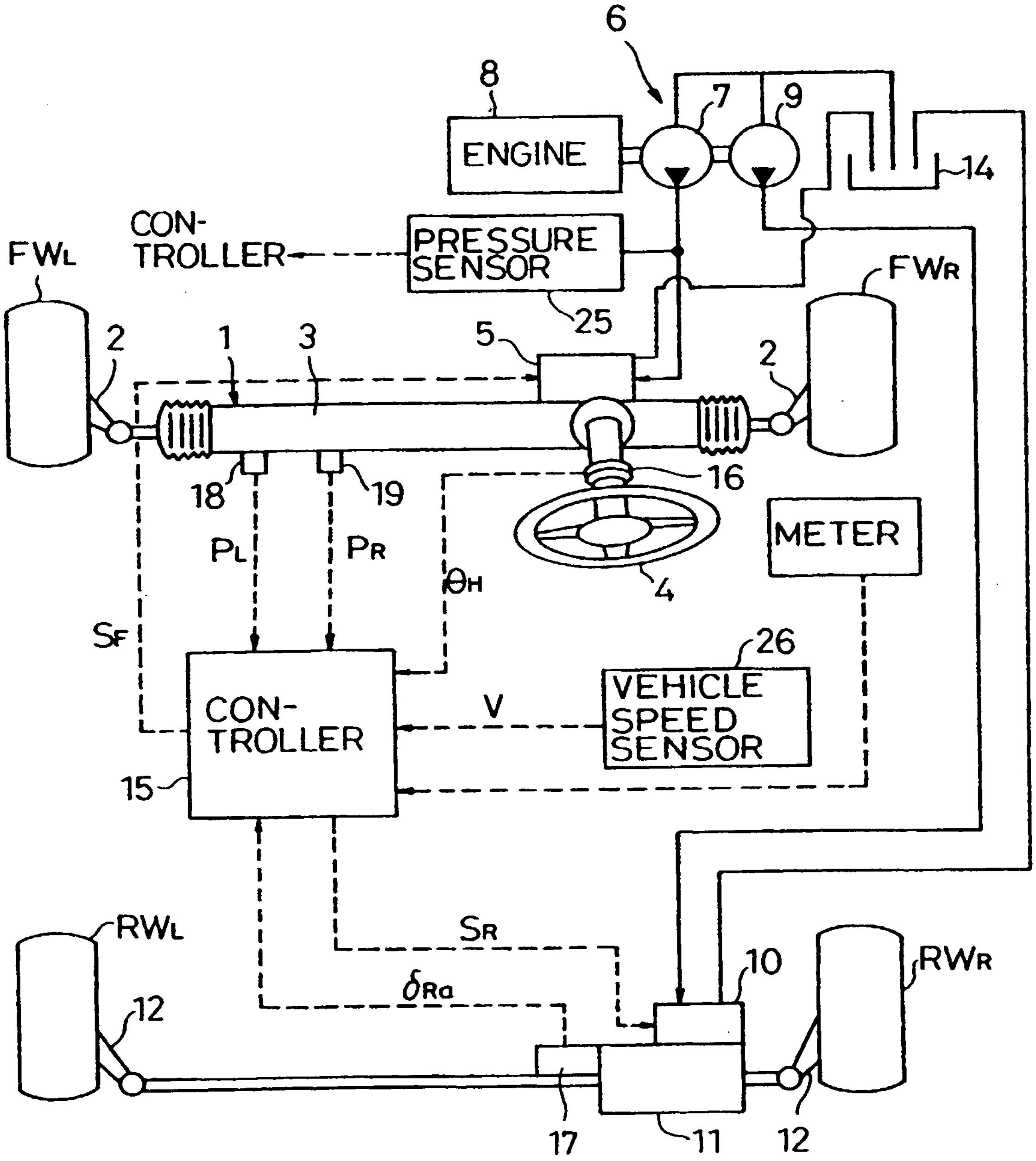

6
8
7
9
ENGINE
14
CON-
TROLLER
PRESSURE
SENSOR
FWL
FWR
25
2
1
3
5
2
16
18
19
PL
PR
θH
4
METER
SF
26
CON-
TROLLER
V
VEHICLE
SPEED
SENSOR
15
RWL
SR
10
RWR
δRa
12
17
11
12

FIG. 2

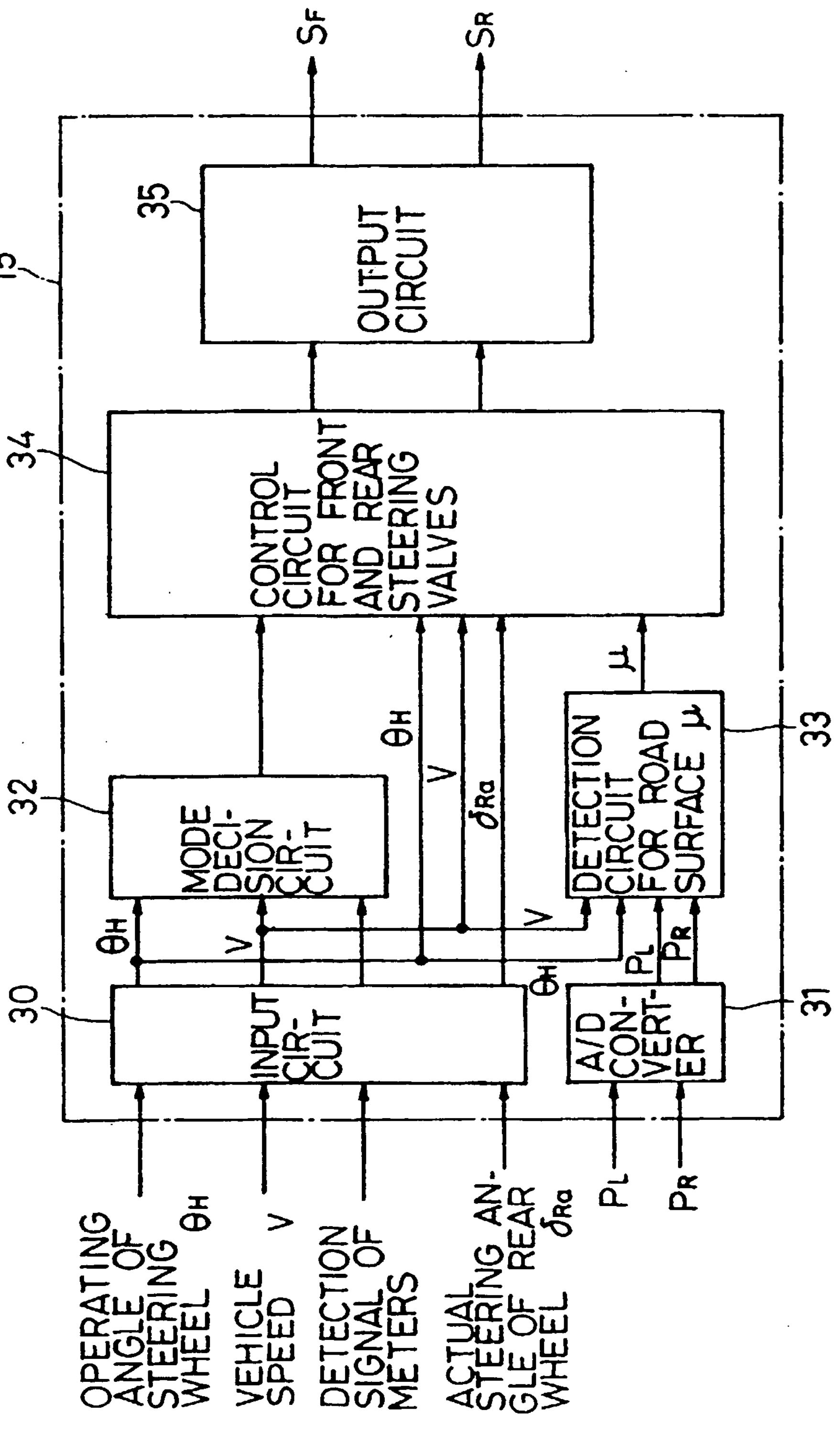

OPERATING ANGLE OF STEERING WHEEL θH
VEHICLE SPEED V
DETECTION SIGNAL OF METERS
ACTUAL STEERING ANGLE OF REAR WHEEL δRa
PL
PR
15
30
INPUT CIRCUIT
31
A/D CONVERTER
32
MODE DECISION CIRCUIT
33
DETECTION CIRCUIT FOR ROAD SURFACE μ
34
CONTROL CIRCUIT FOR FRONT AND REAR STEERING VALVES
35
OUTPUT CIRCUIT
θH
V
δRa
μ
SF
SR

FIG. 3

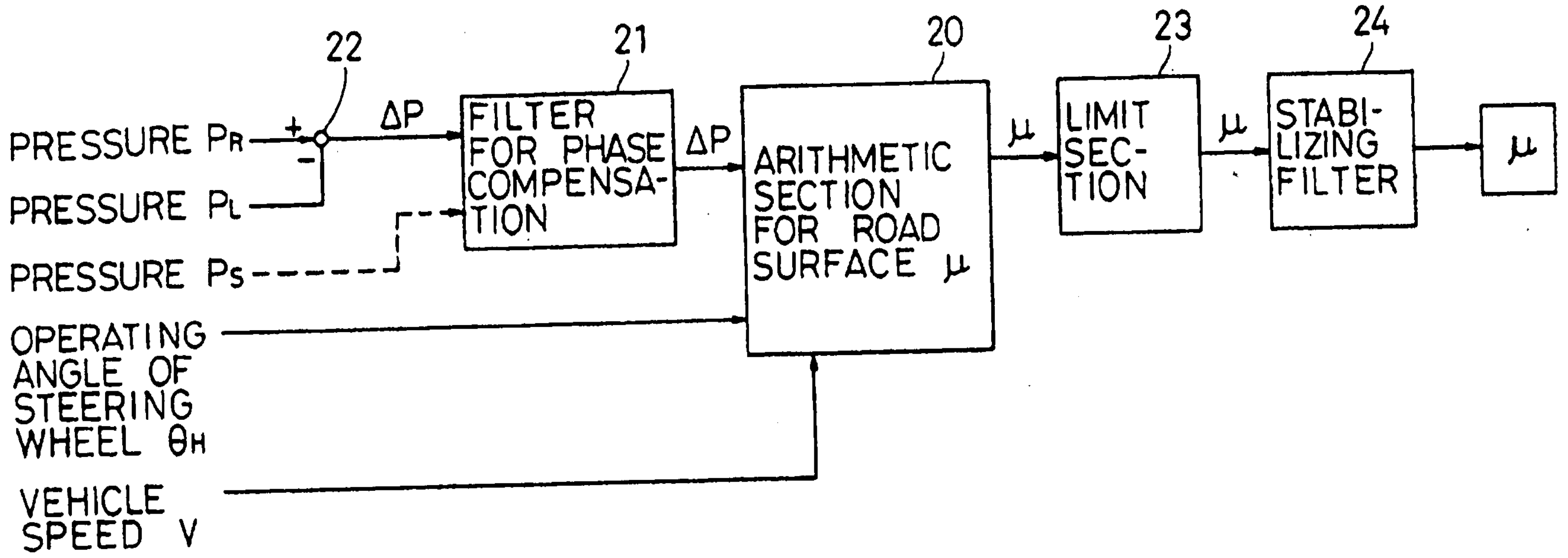

22
21
20
23
24
PRESSURE P_R
PRESSURE P_L
PRESSURE P_S
OPERATING ANGLE OF STEERING WHEEL θ_H
VEHICLE SPEED V
+
-
ΔP
FILTER FOR PHASE COMPENSATION
ΔP
ARITHMETIC SECTION FOR ROAD SURFACE μ
μ
LIMIT SECTION
μ
STABILIZING FILTER
μ

FIG. 4

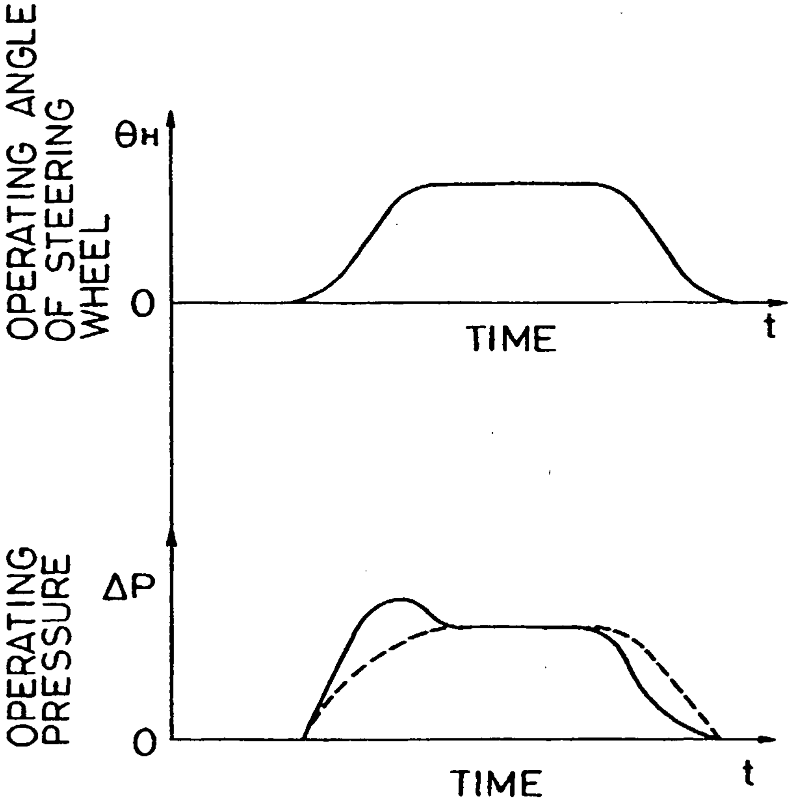

OPERATING ANGLE OF STEERING WHEEL
θH
0
TIME
t
OPERATING PRESSURE
ΔP
0
TIME
t

FIG. 5

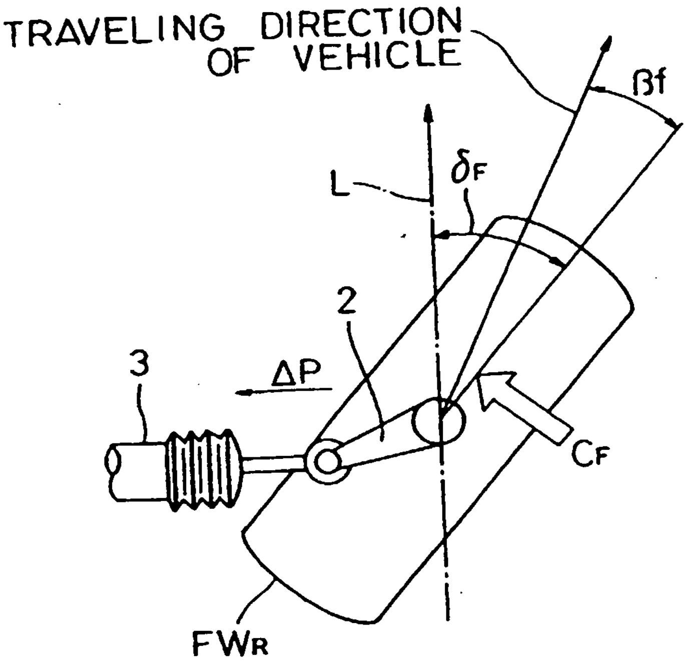

TRAVELING DIRECTION OF VEHICLE
βf
L
δ_F
2
3
ΔP
C_F
FW_R

FIG. 6

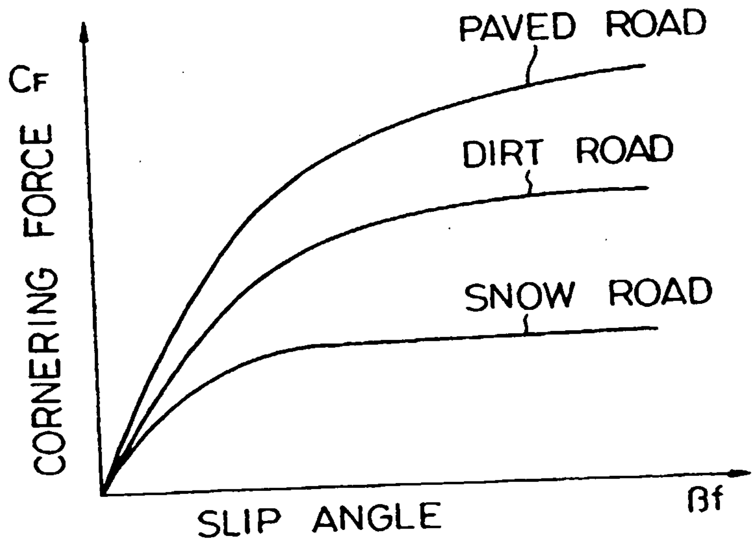

C_F
CORNERING FORCE
PAVED ROAD
DIRT ROAD
SNOW ROAD
SLIP ANGLE
βf

FIG. 7

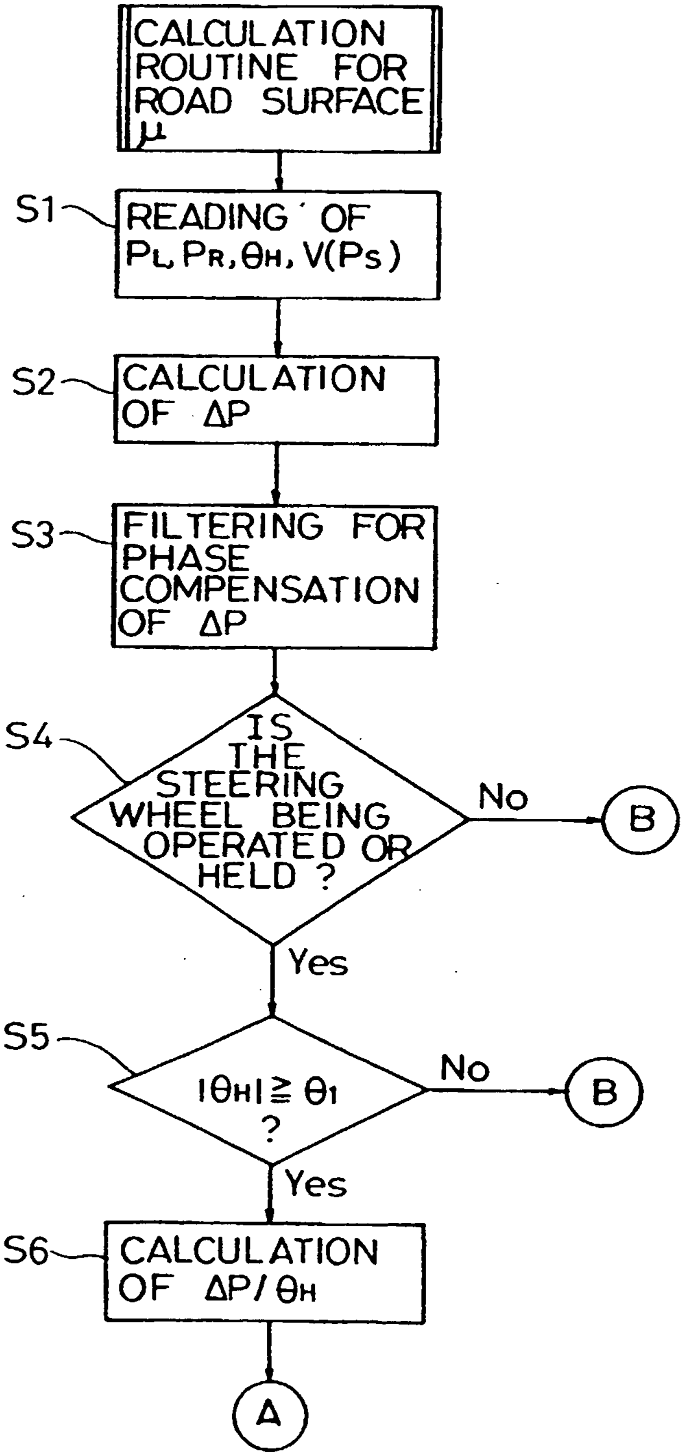

CALCULATION ROUTINE FOR ROAD SURFACE μ
S1
READING OF PL, PR, θH, V(Ps)
S2
CALCULATION OF ΔP
S3
FILTERING FOR PHASE COMPENSATION OF ΔP
S4
IS THE STEERING WHEEL BEING OPERATED OR HELD ?
No
B
Yes
S5
|θH| ≧ θ1 ?
No
B
Yes
S6
CALCULATION OF ΔP/θH
A

FIG. 8

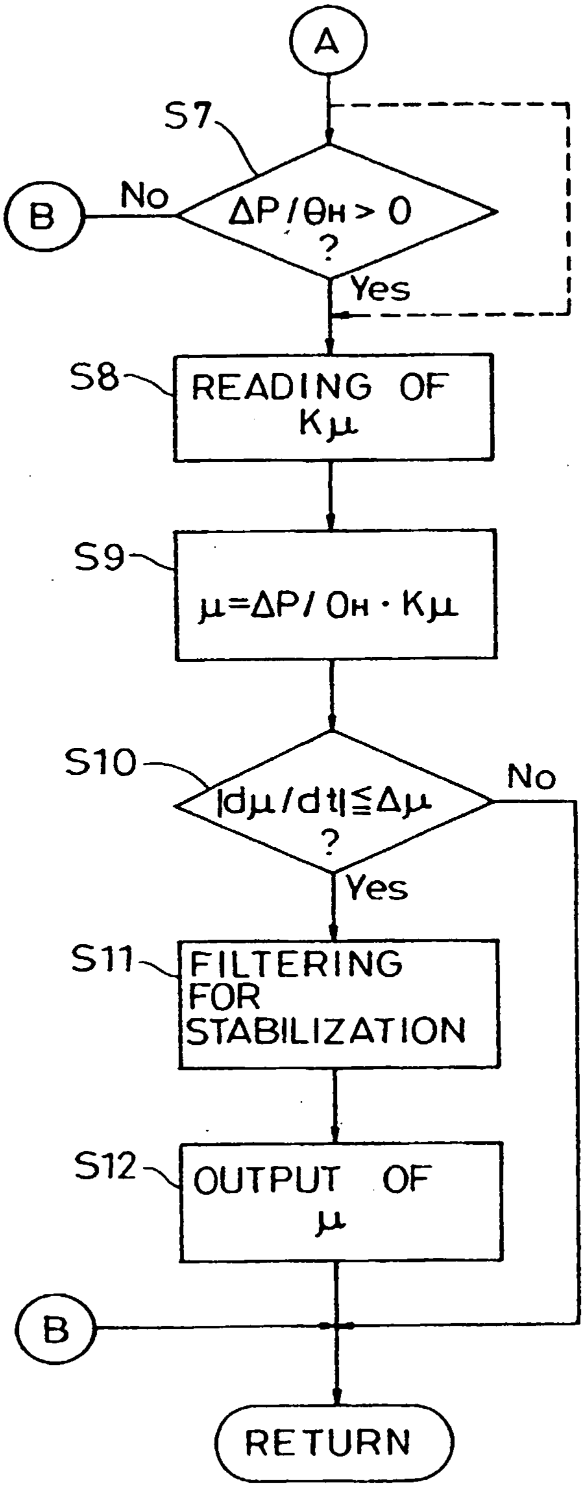

A
S7
No
B
ΔP/θH > 0 ?
Yes
S8
READING OF Kμ
S9
μ=ΔP/ OH · Kμ
S10
|dμ/dt|≦Δμ ?
No
Yes
S11
FILTERING FOR STABILIZATION
S12
OUTPUT OF μ
B
RETURN

FIG. 9

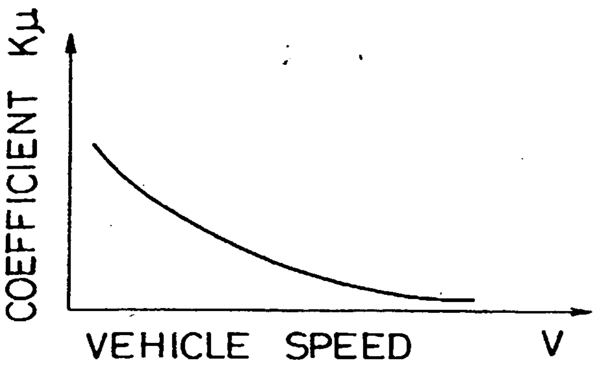
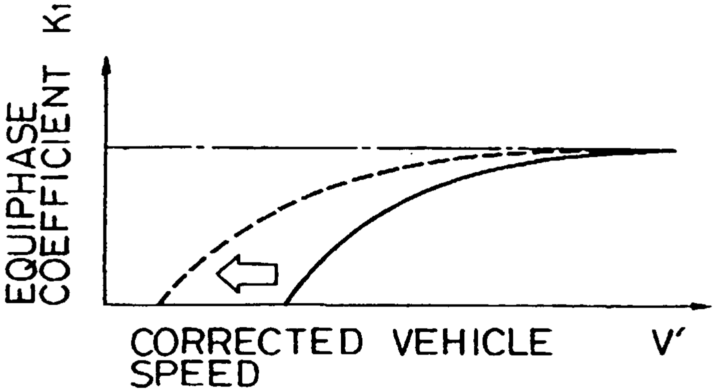

COEFFICIENT Kμ
VEHICLE SPEED
V

FIG. 11


EQUIPHASE COEFFICIENT K1
CORRECTED VEHICLE SPEED
V'

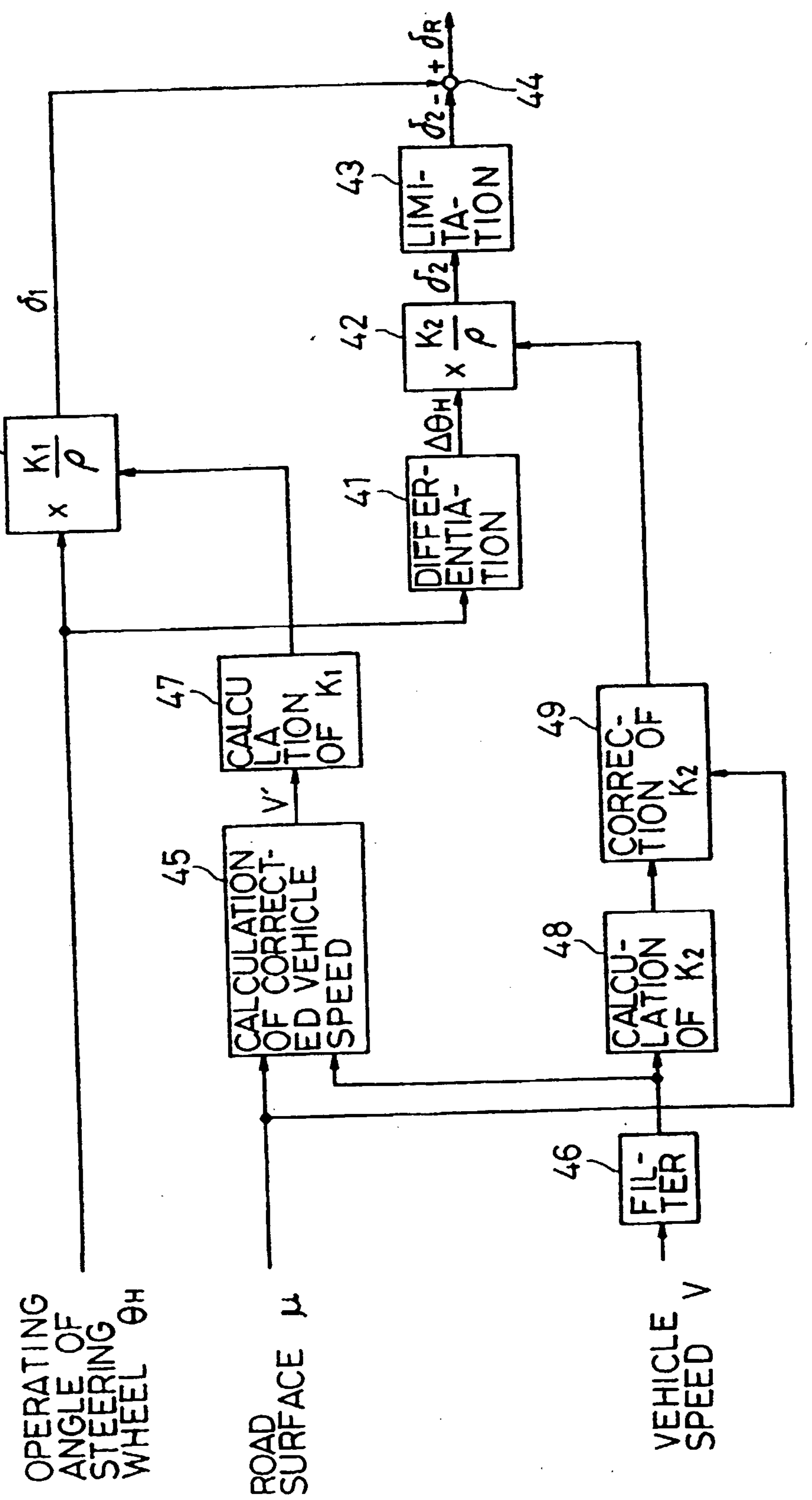


FIG. 10

OPERATING ANGLE OF STEERING WHEEL θ_H
ROAD SURFACE μ
VEHICLE SPEED V
40
$\times \frac{K_1}{\rho}$
δ_1
41
DIFFER-ENTIA-TION
$\Delta\theta_H$
42
$\times \frac{K_2}{\rho}$
δ_2
43
LIMI-TA-TION
δ_2
44
-
+
δ_R
45
CALCULATION OF CORRECT-ED VEHICLE SPEED
V'
46
FIL-TER
47
CALCU LA TION OF K_1
48
CALCU-LATION OF K_2
49
CORREC-TION OF K_2

FIG. 12

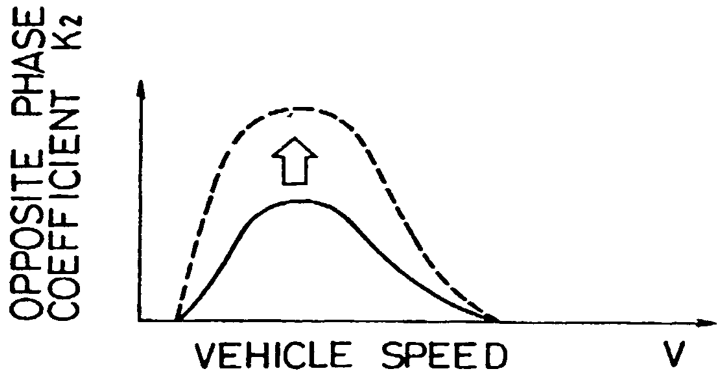
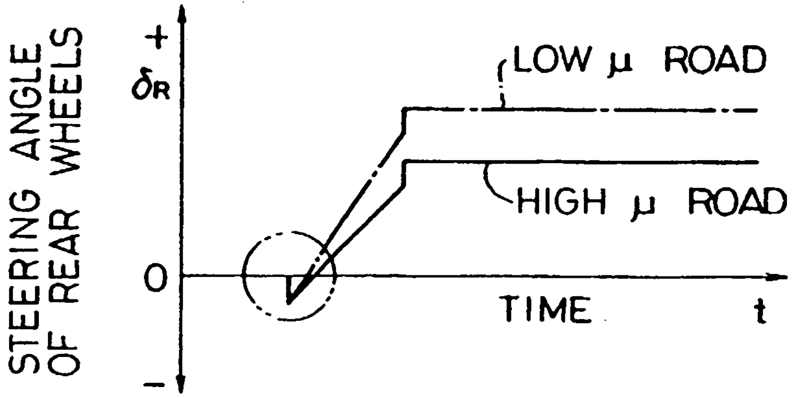

OPPOSITE PHASE COEFFICIENT K_2
VEHICLE SPEED
V

FIG. 13


STEERING ANGLE OF REAR WHEELS
+
δ_R
0
−
LOW μ ROAD
HIGH μ ROAD
TIME
t

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(54) **Method and apparatus for detecting friction coefficient of road surface, and method and system for four-wheel steering ofvehicles using the detected friction coefficient of road surface.**

(57) An method for detecting a friction coefficient (μ) of the road surface according to the present invention comprises a detection step of detecting an operating angle (θ_H) of the steering wheel (4) of the vehicle, a vehicle speed (V) and an operating pressure (Δ P) of the hydraulic power steering unit (1) for the front wheels (FW), and a calculation step of calculating the friction coefficient of the road surface on turning of the vehicle by considering relationships among a slip angle (β f) of the front wheel, the friction coefficient of the road surface and a cornering force (C_F) of the front wheels. The method according to the present invention further includes a step of prohibiting the execution of the calculation step when the steering wheel is turned back, whereby the calculation step is executed only when the direction of the operating pressure of the power steering unit is in the equiphase with the operating direction of the steering wheel. Also, the four-wheel steering system according to the present invention has a rear steering actuator (11) for steering the rear wheels (RW) so as to increase the steering angle of the rear wheels as the friction coefficient of the road surface calculated by the above-described method decreases.

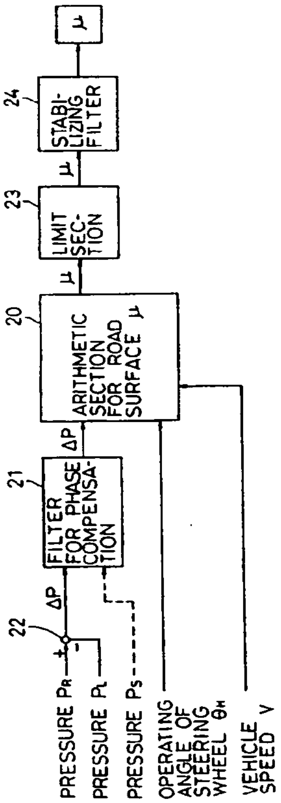
μ
24
STABI-LIZING FILTER
μ
23
LIMIT SEC-TION
μ
20
ARITHMETIC SECTION FOR ROAD SURFACE μ
ΔP
21
FILTER FOR PHASE COMPENSA-TION
ΔP
22
+
-
PRESSURE PR
PRESSURE PL
PRESSURE PS
OPERATING ANGLE OF STEERING WHEEL θH
VEHICLE SPEED V

FIG. 3

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Jouve, 18, rue Saint-Denis, 75001 PARIS

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EUROPEAN SEARCH REPORT

Application Number
EP 91306077

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
A	WO-A-8802483 (ROBERT BOSCH) * claims 1,3,7 *	1
Y,D	FR-A-2558130 (HONDA GIKEN KOGYO) * page 17, line 4 - page 20, line 15; figure 5 *	12,19
A,D	* page 10, line 27 - page 12, line 9; figure 2; page 17, line 14 - page 19, line 8; figure 5 *	1
A,P	US-A-4940103 (MOMIYAMA) * column 5, line 45 - column 6, line 16; figures 1,2,5,6 *	1
A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 323 (M-634), 21 October 1987; & JP-A-62105776 (NISSAN MOTOR) 16.05.1987 * the whole document *	1
A	DE-A-3409040 (FUGMANN) * claim 1; figure 2 *	1
Y	GB-A-2210834 (FUJI) * page 5, paragraph 1 - paragraph 2; page 7, last paragraph; page 9, last paragraph - page 10, paragraph 1; figures 2,5,8 *	12,19
A	FR-A-2622166 (JIDOSHA KIKI) * figure 3 *	12

CLASSIFICATION OF THE APPLICATION (Int. Cl.5)

G01N19/02
G01L5/20
B62D5/06
B62D7/15
// (B62D111:00,
B62D121:00)

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G01N
G01L
B62D
B60R

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	04.03.1992	BROYDE, M.P.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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L : document cited for other reasons
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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid,

namely claims:

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

1. Claims 1-11
   Method and apparatus for detecting a friction coefficient on a vehicle

2. Claims 12-19
   Method for operating a four wheel steering system and four wheel steering system

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid,

namely claims:

☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims.

namely claims: